Diagnosis of Effectiveness of HVAC System and Energy Performance of Osaka-Gas Building through Retro-Commissioning
Part 2 Handling the Data Produced by BEMS and Some Results of Analyses

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ABSTRACT

In case of retro-commissioning, utilization of operational data would be very important. We obtained BEMS data of 2003 and from 2009 to 2012. Operation patterns of heat source plants vary from 2003 to 2012 according to change in plant's operational strategy. 90 percent of primary energy was consumed by generators and chillers. Since the plant is run by combined heat and power system, waste heat from the generators is recovered and used for chillers. The efficiency of the generators had been kept around 0.35 which was almost same as specification of the machines. The efficiency of the entire system, however, was decreased, especially in intermediate seasons, or spring and autumn. During these seasons, waste heat from generators which were operated constantly through a year could not be utilized by chillers.

INTRODUCTIONS

On energy performance evaluation of the office building equipped with a gas co-generation system through commissioning, the outline of building, commissioning plan and concepts of evaluation indices were presented in Part 1. In this report, performance evaluation of energy system including co-generation was conducted.

Prior to the evaluation, since a co-generation system produce both electricity and heat, which are not same quality in the second law of thermodynamics view point, some indices were considered. The operating data produced by a building energy management system (BEMS) is usually in inconvenient form for commissioning evaluation. The annual operational data are divided into daily individual files. For annual analysis, each file has to be integrated into one file and treated by scripts for R language.

DESCRIPTION OF THE SYSTEM

The energy system consisted of two generators and absorption chillers. The generators had been operated by electrical output control with maximum electric generated during operation. Two chillers were heat recovery type absorption and other two were gas combustion type. The heat recovery type had operational priority to gas combustion ones. The specification of the system is shown in Table 1 and a schematic diagram is shown in Figure 1. The scope of the system was identified in Figure 2.

PERFORMANCE INDICES FOR CO-GENERATION

Since co-generation produce heat and power, evaluation of performance becomes complicated. Shomoda (Shimoda, 1998) discussed performance in very wide range, such as envriomental, economical, social, safty, and flexisiblity points of view. Some evaluation and quality indices taking account of availability of heat and power were proposed (Enomoto, 2007). The way to evaluate heat efficiency was discussed (Kawashima, 2007) assuming that it was equivalent to power out put. We have defined indicies show below to evaluate the plant efficiency.

<u>Primary Energy Based Efficiency</u>

The index, which is calculated by dividing the heat recovered and power generated by input in primary value is shown in Equation (1).

$$\frac{Q_{DC} + Q_{DH} + E_{CGS} \cdot k_0}{(E_S + E_P) \cdot k_1 + C_P + C_{CGS}} \quad (1)$$

<u>Equivalent Electricity Efficiency</u>

Since electricity is not equivalent to heat considering availability, the amount of heat and power cannot be used for evaluation. The index shown below is calculated heat by multiplying electricity conversion coefficient. This is known as a PURPA Minimum Qualifying Facility (QF) if the coefficient is 0.5.

Table 1. List of main equipment

G-1 G-2	Generators for co-generagtion	Power Output 280kW Gas Consumption 60.6Nm^3/h Nominal Efficiency 40% Heat Recovery / Efficiency 241kW / 34.3%、Overall Efficiency 74.4%
R1 R2	Waste heat recovery type absorption chillers	Cooling Capacity 1,400 kW (12°C～7°C) Heating capacity 1177 kW (45.8°C～50°C) Condensation Water 32°C～37.7°C Heat recovery pumps 5.5kW× 2
CT-1,2	Cooling towers	Fan Capacity 11k×2
CDP-1,2	Condensation water pumps	200φ×6667 L/min×300kPa×55kW×3φ×440V
CHP-1,2	Primary pumps	200φ×4032 L/min×150kPa×18.5kW×3φ×440V
R3 R4	Gas combustion Absorption Chillers	Cooling Capacity 1758kW (12°C～7°C) Heating Capacity 1163kW (51.7°C～55.0°C) Condensation water 32°C～37.0°C
CT-3, 4	Cooling Towers	Fan Capacity 11kW×3φ×440V×2
CDP-3,4	Condensation water pumps	200φ×8333 L/min×300kPa×75kw×3φ×440V

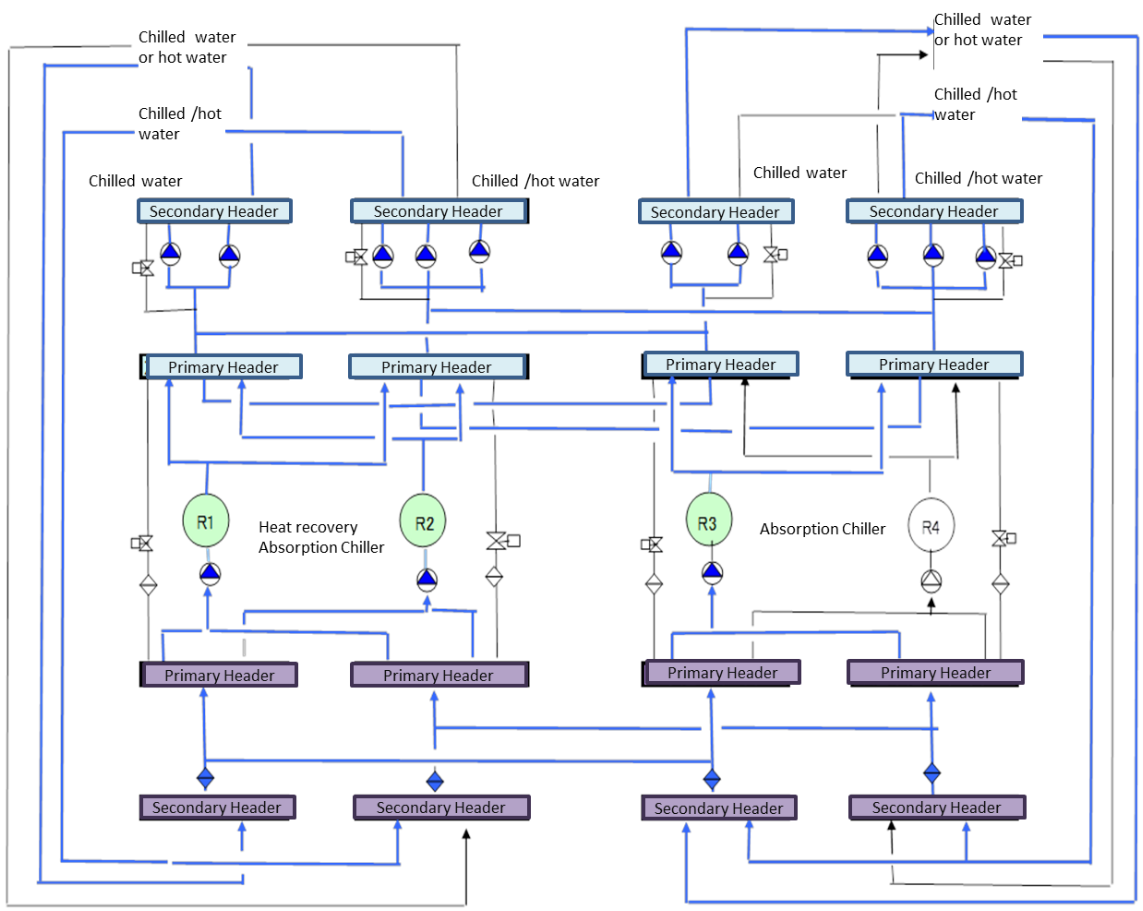

Figure 1. Schimatic diagram of the system

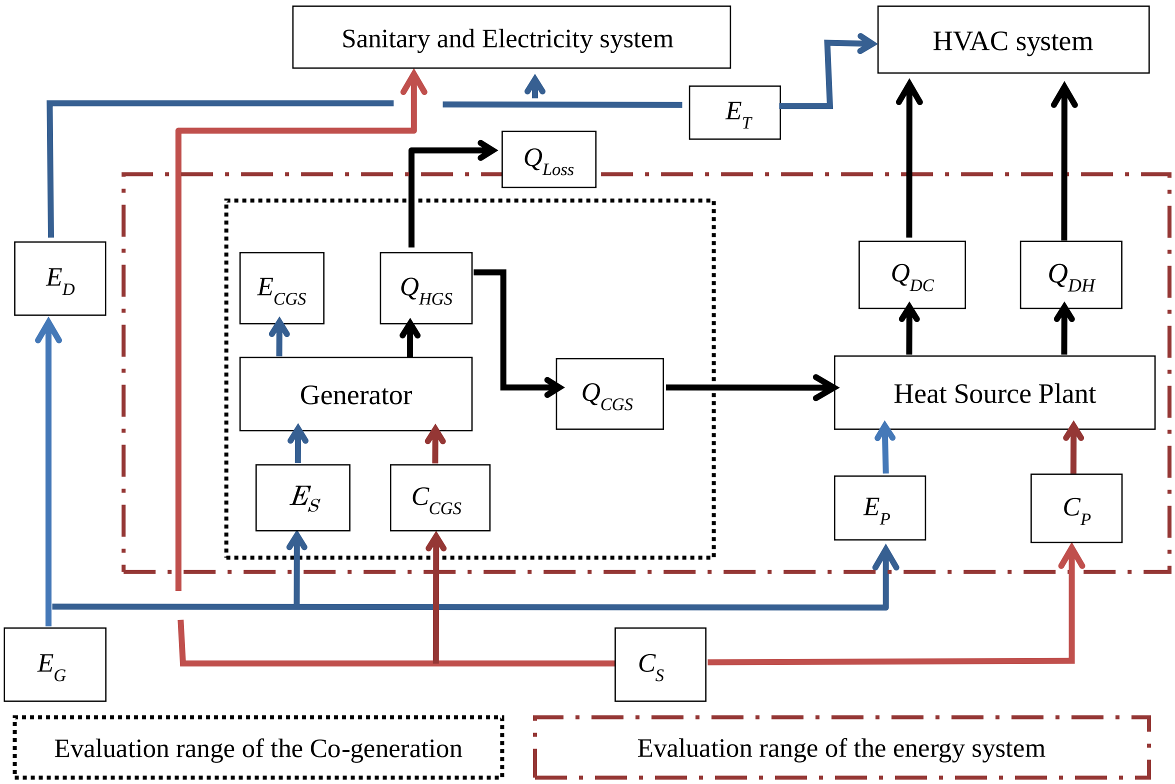

Figure 2. Energy flow for analysis

$$\frac{E_{CGS} + Q_{CGS} \times X}{E_s + C_{CGS}} \quad (2)$$

Equivalent Input Efficiency

The index shown above assumed the conversion coefficient for heat. Assuming equivalent energy of boiler if the recovered heat was produced by boilers, an index, in which the assumed energy was subtracted from input energy, can be defined.

$$\frac{E_{CGS}}{E_s + C_{CGS} - Q_{HGS}/\eta_B} \quad (3)$$

Equivalent Heat Efficiency

An index can be defined if the restored heat was obtained by heat pump chillers.

$$\frac{E_{CGS} + Q_{CGS} \times Y}{E_s + C_{CGS}} \quad (4)$$

Boiler Equivalent Efficiency

Other index can be calculated focusing on the heat. Assuming the electricity generated by co-generation was replaced by utilities, the energy for the electricity was calculated by the efficiency of generation for the utilities.

$$\frac{Q_{CGS}}{C_{CGS} + E_S - E_{CSG}/\eta_E} \quad (5)$$

DATA PROPERTIES FROM BEMS

Table 2 shows the properties of data obtained from BEMS. The objective of data acquisition for the BEMS at the design phase was monitoring of subsystem or equipments. Not all properties needed for performance evaluation was presented. Some values, such as flow rate of chilled, hot and heat recovery were estimated from operational hours.

Table 2. Data properties obtained form BEMS

Equipments	Temperature	Flow rate	Energy	Others
Chiller	Inlet and outlet	n/a	Gas	Operation Hours
Cooling tower	Inlet and outlet	n/a	n/a	n/a
Primary Pumps	n/a	n/a	n/a	n/a
Secondary Pumps	n/a	n/a	n/a	Inverter output
Heat load	n/a	L/min	kWh	
CGS	n/a	n/a	Gas	kWh

At ordinary BEMS system in Japan, measured data is presented in forms of daily reports which are designed for printed in papers. Since the data is delivered in daily individual files, integration of each files into one annual file is needed. For this purpose, a script of R language was written, and integrated files were used for analysis.

For energy evaluation, the higher heat value of gas, or 45MJ/m^3 was used for evaluation of absorption chillers. The lower heat value of gas, or 40.6MJ/m^3 was used evaluation of generators.

RESULTS

Efficiency Of Chillers Over Years

It had been 9 years since the facility was renovated. Deterioration of machines, especially of chillers was expected. since only one flow rate was measured, attempt to estimate coefficient of performance (COP) was conducted for the period when single chiller was in operation. Estimations were conducted for gas combustion absorption chillers.

Figure 3 shows histograms of estimated COP over years. COP in 2003, or completion year distributed in higher value comparing the value in 2009 and 2010. Since the operations for estimated period were in small partial load, it was impossible to conclude the deterioration.

Primary Energy Consumptions

The amount of primary energy consumption is shown figure 4. The consumptions of chillers and generators were calculated from measured gas consumption from BEMS data. The primary energy of pumps were estimated by multiplying nominal electricity consumption and operational hours. The dominant part of primary energy was generators and absorption chillers. The difference of generator consumption due to the change in operational strategy in between 2003 and 2009.

Primary Energy Efficiency

Primary energy efficiency defined by equation (1) is shown in Figure 5. Although the efficiency of the whole year is 0.7, it fluctuated annually. The efficiency increased in summer and winter and decreased in spring and fall, or intermediate season. The waste heat from the generators utilized by absorption chillers. In intermediate season, amount of waste heat surpassed heat demand because the generators operated by electrical output control. Unused heat was released to ambient through cooling towers.

Boiler Equivalent Efficiency

Figure 6 shows the boiler equivalent efficiency based on Equation (5). For the system, Equation (5) was modified to Equation (6)

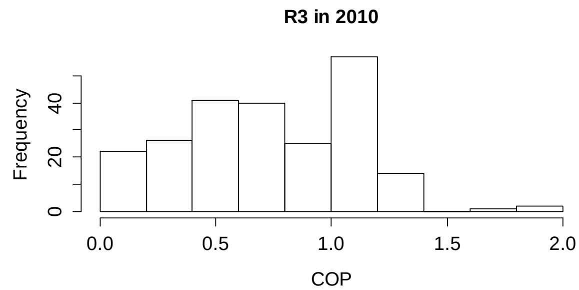

Figure 3-a. Estimated COP of R3 in 2010

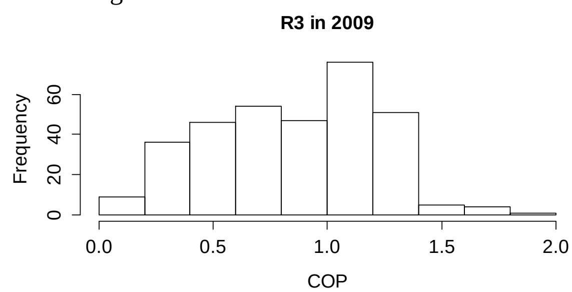

Figure 3-b. Estimated COP of R3 in 2009

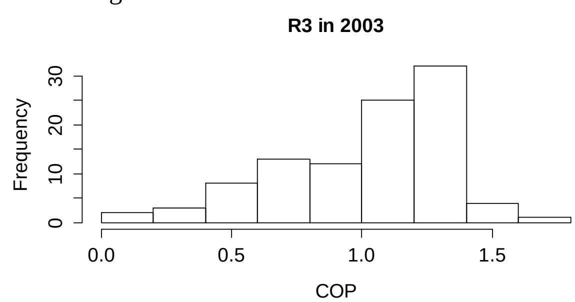

Figure 3-c. Estmated COP of R3 in 2003

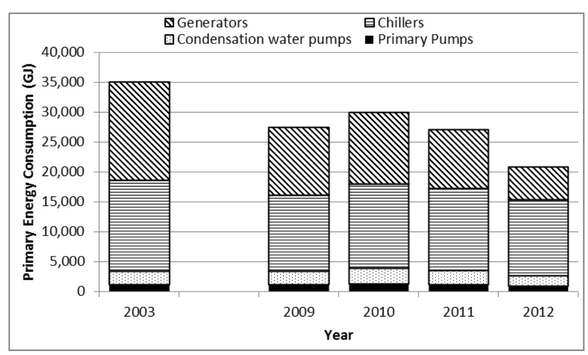

Figure 4. Yeary primary energy consumption

$$\frac{Q_{DC}+Q_{DH}}{C_s+E_P+E_S-E_{CGS}/\eta_E} \quad (6)$$

As electricity part is subtracted from input energy,

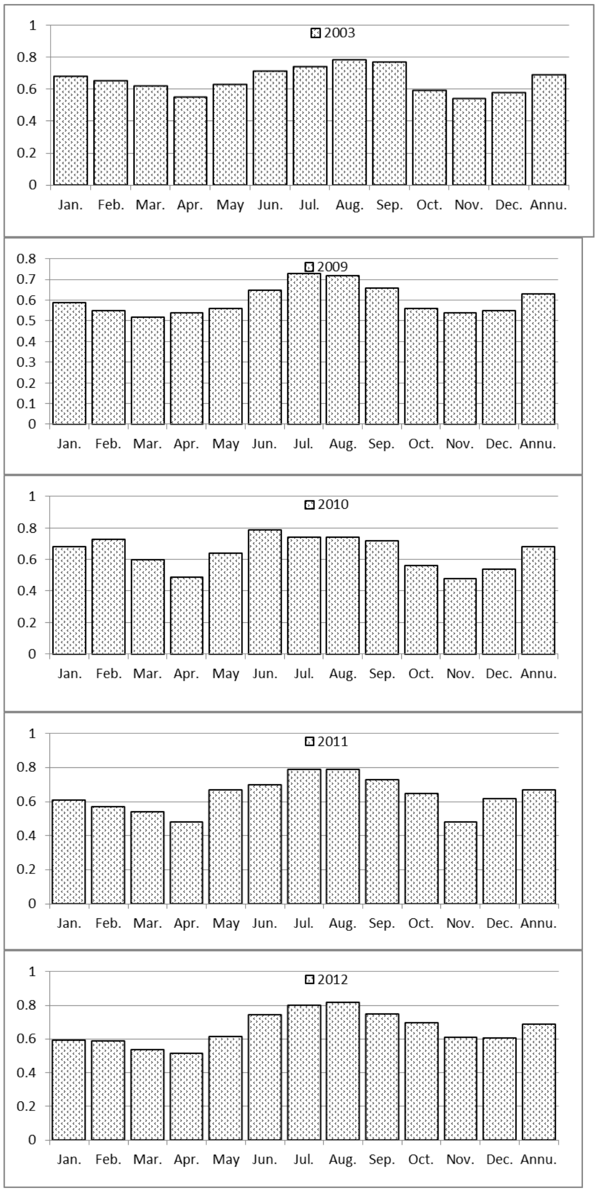

Figure 5. Primary Energy Efficiency

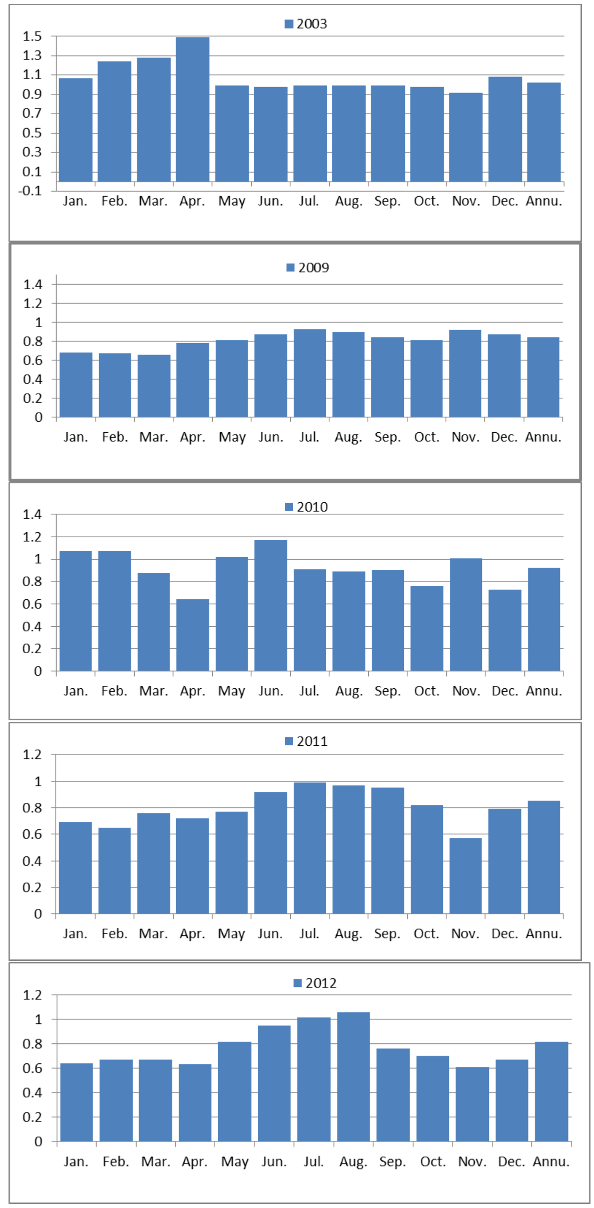

Figure 6. Boiler equivalent efficiency

the value realized over 1.0 while energy input was small.

Figure 7 shows primary energy efficiency limited to the generators. The generation efficiency continued0.4 throughout the years. Since the flow rates of waste hot water were not measured, the values were estimated from a nominal capacity of pumps and operational hours. During 2012, since a modification for BEMS system was made, data for several month was missing. The efficiency including waste heat recovery fluctuate as well as primary efficiency of the system.

DISCUSSIONS

As shown in Figure 5 primary efficiency of the system decreased in spring and autumn. The waste heat from generators was used in heat recovery absorption chiller. The intermediate season, such as spring and autumn, as cooling or heating load for chillers were not sufficient to utilize waste heat, the heat was discharged into atmosphere by cooling towers. The generators were operated by output control of electricity which was decided by contract of the building. The efficiency would be increased if operation of generators was revised in the intermediate season.

From 2011, the operational strategy had been changed. The ordinary chillers had operational priority to heat recovery chillers. Therefore, the amount of heat

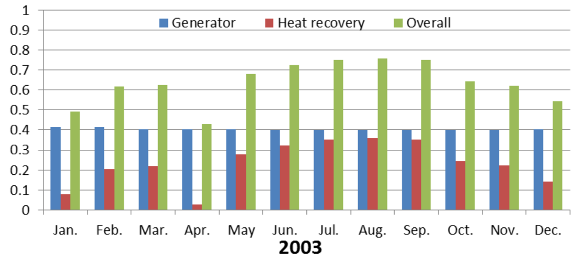

Figure 7-a. Efficiency of co-generation in 2003

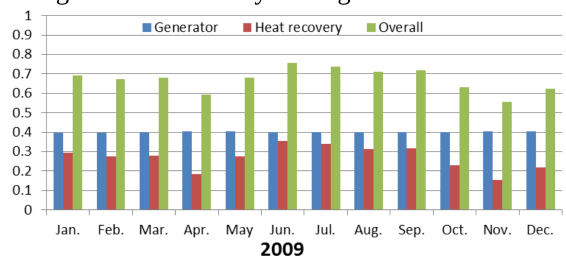

Figure 7-b. Efficiency of co-generation in 2009

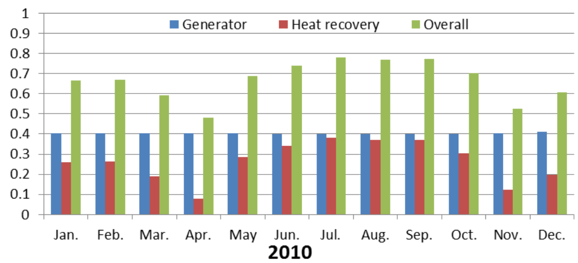

Figure 7-b. Efficiency of co-generation in 2010

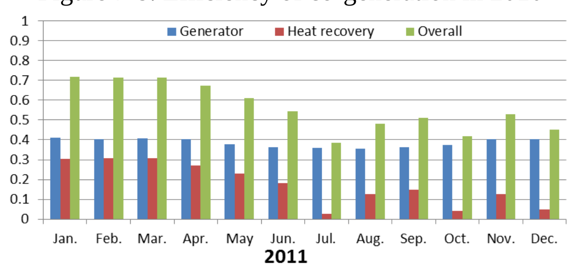

Figure 7-c. Efficiency of co-generation in 2011

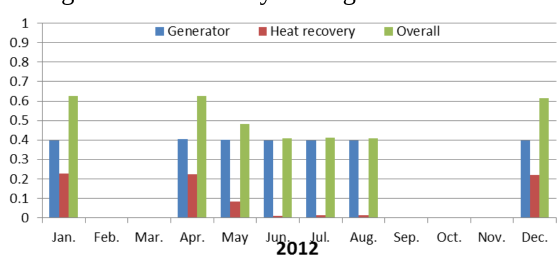

Figure 7-d. Efficiency of co-generation in 2012

recovery was decreased shown in Figure 7-c and 7-d. The reason of change was that COP of heat recovery chillers were lower than ordinary chillers. It was considered that the difference of COP could overcome the amount of heat recovery. In Figure 5, less siginifcance was seen in primary energy efficiency after 2011.

CONCLUSIONS

Energy analysis was conducted using BEMS data of the Osaka gas building. The obtained data was restricted to maintenance purpose. Evaluations were conducted by assuming some values from design specifications.

Primary efficiency for whole year achieved nearly 70 %. However, in the intermediate season, efficiency decreased because the waste heat by output control was not used. Revision of generator operation or utilization of waste heat in intermediate season would be needed to improve the efficiency of the system.

NOMENCLATURES

Q_{DC} : Cooling demand
Q_{DH} :Heating demand
C_S : Gas consumption of whole system
C_P :Gas consumption for chillers
E_P: Electricity consumption for chillers
E_{CGS} : Generated power
Q_{HGS} :Heat recovery
Q_{CGS} : Utilized heat from recovery
Q_{Loss}: Unused heat from recovery
C_{CGS}: Gas consumption of generators
E_s: Electricity consumption of generators
E_D: Electricity Demand
E_G: Purchased electricity
E_T: Electricity consumption for HVAC sytem
k_0:Conversion factor for electricity
k_1:Primary conversion factor for electricity
η_E: Generation efficiency of utitliy (37%)

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